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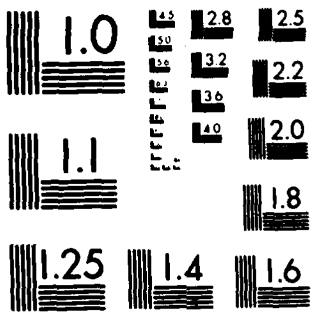

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APPLICATION OF MILITARY LUBRICANTS IN COMMERCIAL HYDRAULIC/POWER TRANSMISSION SYSTEMS AND COMPONENTS

FINAL REPORT
AFLRL No. 170

By

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Under Contract to

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The MACI Hydraulic System and Components Program was selected to perform technical evaluation and assessment of commercially available qualified and fielded military specification lubricants and to determine if such oils can be used as hydraulic lubricants in Army commercial Construction Equipment (CCE) and Selected Material Handling Equipment (SMHE).

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ABSTRACT, Continued.

Eight military specification lubricants: one MIL-H-46001C Grade 3, one MIL-L-2104C Grade 10W, one MIL-L-46167 Arctic equivalent to Grade OW-20 and five MIL-L-46152B Grade 15W-40 were extensively evaluated using eleven selected tests required by manufacturers and one test developed by AFLRL in conjunction with John Deere personnel.

From the data developed, the Army lubricants passed 90 percent of all the tests. Also, from the data presented, it appears that the MIL-L-46152B Grade 15W-40, the MIL-L-2104C Grade 30, the majority of the grade 10W, and possibly the MIL-H-46001C Grade 3 and MIL-L-46167 equivalent to Grade OW-20 (in cold climates) lubricants are good potential candidates for use as hydraulic and power transmission lubricants within the Army CCE/SMHE system.

In a survey, twenty-four manufacturers of hydraulic and power transmission systems and components were asked to identify the equipment which would not operate properly with military lubricants. Some of the manufacturers expressed the following concerns: potential wet-brake chatter noise, pump performance and differential gear wear problems.

FOREWORD

The work reported herein was conducted at the U.S. Army Fuels and Lubricants Research Laboratory (AFLRL), Southwest Research Institute, San Antonio, TX, under Contract No. DAAK70-80-C-0034 and covers the period June 1983 - October 1983. The work was funded by the U.S. Army Mobility Equipment Research and Development Command (MERADCOM) currently Belvoir Research and Development Center, Ft. Belvoir, VA. Contracting officer's representative was Dr. M. Kolobielski, Fuels and Lubricant Division/DRDME-VF (currently STRBE-VF), and the technical monitor was Mr. M.E. LePera, Chief, Fuels and Lubricants Division (DRDME-VF) (currently STRBE-VF), MERADCOM.

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I. INTRODUCTION

Recognizing the need for modernization as well as being confronted with decreasing R&D budgets, the Army adopted a policy of procuring construction-type equipment (CCE) from commercial sources.(1)* The purchase of standard "off-the-shelf" equipment has been practiced for the last decade. Today the majority of the construction equipment and selected material handling equipment (SMHE) utilized by the Army is of the commercial or modified commercial type. The balance is procured under government-controlled drawing packages. Although obvious advantages exist for this policy, certain problems require resolution to make the CCE and SMHE program successful. These CCE and SMHE items utilize hydraulic systems composed of various commercial components. The fluids used in these hydraulic systems are considered as components of the total system and are frequently provided under commercial proprietary fluid specifications. Using the various manufacturer's specifications would obviously lead to a proliferation of proprietary hydraulic fluids creating a logistic burden to the supply system. However, the use of fluids not authorized by the equipment manufacturers could lead to the loss of equipment warranty, and many of the manufacturers are reluctant to permit use of other than specified fluids in their equipment.

With the introduction of the CCE program, John Deere and Company was awarded a contract to furnish a CCE item (front loader/backhoe tractor) which introduced the first wet-brake equipped vehicle into the Army in 1975. Since subsequent contract procurements could be awarded to other companies, there was great concern within the Army as to potential supply problems since each of these companies require that its own proprietary hydraulic fluid be used. Some of these companies indicated that MIL-L-2104C combat/tactical engine oils would not perform satisfactorily in their equipment systems. With this problem in mind, MERADCOM initiated a test program in 1975 to establish the performance levels of fifteen lubricants, which included existing military specification lubricants, and several commercial and Government stocked

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*Underscored numbers in parentheses refer to references listed at the end of report.

hydraulic and power transmission fluids in relation to the John Deere JDM-J20A factory and service fill specification. Only one of the lubricants, a MIL-L-2104C Grade 10W passed the JDM-J20A specification and was field tested.(2) From this work and from previous experience, the only way to differentiate between acceptable and unacceptable components has been extensive testing of the equipment. This problem has existed because no standardized requirements and test methods have been available to component manufacturers or users. Therefore, this project was initiated in April 1980 as an important element in MERADCOM's overall Military Adapation of Commercial Items (MACI) Hydraulic Systems and Component Program.

II. OBJECTIVE

The specific objective of this MACI program is to perform technical evaluation and assessment of selected military specification oils and to determine if such oils can be used as hydraulic fluids in Army Commercial Construction equipment and selected material handling equipment.

III. INITIAL WORK PHASE SUMMARY

Nine military specification lubricants which included: six oils qualified under MIL-L-2104C, Grade 10W and Grade 30; two available multiviscosity lubricants satisfying MIL-L-2104C engine lubricant requirements, and one oil qualified under MIL-L-46167, were evaluated using ten selected tests required by various equipment manufacturers.(3)

From these data, most test lubricants were considered borderline to excellent. The MIL-L-46167 oil, equivalent to Grade 0W-20, was considered unacceptable because the product failed to meet the pump wear and frictional requirements. The borderline areas of the lubricants appeared in frictional characteristics, slower hydraulic system response times, and more wet brake chatter, none of which was considered excessive to the point of substantially hindering operation. Two lubricants, a MIL-L-2104C Grade 10W oil and

Grade 30 had excellent results. The Grade 10W lubricant is also the lubricant which passed all the John Deere JDM-J20A specification requirements in an earlier program,(2) and was undergoing field evaluation.

Also, three lists were prepared to help in future work. One list contained all the available fluid specification requirements for the suppliers of hydraulic/power transmission systems, the second list contained all the present and planned CCE/SMHE in the Army inventory, and the third list included the manufacturers of the hydraulic/power transmission components and drives used in each type of equipment.

IV. TEST DETAILS

A. Test Lubricants

Numerous lubricants, available in the Military supply system, were selected for evaluation. The lubricants were products approved under specifications MIL-H-46001C (4), MIL-L-21260C (5), MIL-L-2104C (6), MIL-L-46167 (7), and MIL-L-46152B (8). Various rationales were used in selecting these specification products. MIL-H-46001C oils possess exceptional antiwear characteristics in machine tools hydraulic applications. Since this specification has no provision for frictional tests, it would be advantageous to know the friction characteristics of these lubricants. MIL-L-21260C lubricants are employed extensively as a preservative compound usable until the initial scheduled oil change. Since they are currently used in power shift transmission applications, these products should be considered as candidates for construction and material-handling equipment. The MIL-L-2104C, Grade 10W, oil is a new qualified product designated as a reference lubricant for proving ground and equipment acceptance testing. This oil replaces the previous reference product which has been tested in the initial phase of this program. A MIL-L-46167 lubricant had also been evaluated during the initial phase of this program. The specific product selected for this testing had a different formulation than the oil previously used. It should be noted that operation in very low temperature regions would necessitate the use of

MIL-L-46167 lubricant. It was planned to evaluate MIL-L-2104D, Grade 15W-40 products. Since the D revision had not been issued prior to the start of testing, five Grade 15W-40 MIL-L-46152B oils, which were potential candidates for qualification under the proposed MIL-L-2104D specification, were randomly selected from the available MIL-L-46152B products. It is expected that Grade 15W-40 oils will extensively replace the current Grade 10W and 30W products used in Military equipment.

Each of the test lubricants was assigned a numerical code for use in this program. Table 1 summarizes the assigned code designation along with the specification and grade of each product. Eight lubricants were extensively evaluated. Four lubricants--8, 9, 11, and 19--were submitted only to the screening procedure, the TO-2 test. Lubricant 20 was previously tested under another program, but it is included here to show the satisfactory friction and antiwear properties of all 15W-40 lubricants.

TABLE 1. TEST LUBRICANTS EVALUATED

No.	Grade	Specification	Description
8	30*	MIL-L-2104C	Army Fielded Oil
9	30*	MIL-L-2104C	Army Fielded Oil
10	Grade 3	MIL-H-46001C	Army Fielded Oil
11	10	MIL-L-21260C	Army Fielded Oil
12	10W	MIL-L-2104C	Army Fielded Oil
13	ARCTIC**	MIL-L-46167A	Army Fielded Oil
14	15W-40	MIL-L-46152B	Army Fielded Oil
15	15W-40	MIL-L-46152B	Army Fielded Oil
16	15W-40	MIL-L-46152B	Army Fielded Oil
17	15W-40	MIL-L-46152B	Army Fielded Oil
18	15W-40	MIL-L-46152B	Army Fielded Oil
19	15W-40	MIL-L-46152B	Army Fielded Oil
20	15W-40	MIL-L-46152B	Army Fielded Oil

* Lubricants 8 and 9 were TO-2 test reruns from previous work.
**Equivalent to Grade 0W-20

The specification lubricants were subjected to twelve selected test requirements discussed in the following section.

B. Criteria for the Selection of Test Procedures

At the present time, there is no single common specification for hydraulic and power transmission fluids. The manufacturers of commercial construction and material-handling equipment issue their own proprietary specifications for hydraulic and power transmission fluids. An ASTM panel is working towards development of a uniform specification for multipurpose power transmission fluids. To aid in selection of the test procedures performed in the program, a listing was made, during the first phase, of the various manufacturer's requirements for hydraulic and power transmission fluids.(3) This report also included the specification requirements proposed by the ASTM Panel. From these data, twelve tests were selected which were determined to be best suited to this program.(2,3) These tests are shown in Table 2.

TABLE 2. LUBRICANT PERFORMANCE TESTS

Test	Description
A.	Wet-clutch Friction Retention (Caterpillar, TO-2)
B.	Wet-clutch Friction Retention [Detroit Diesel Allison (DDA), C-3]
C.	Pump Anti-Wear Properties (DDA, C-3)
D.	Seal Compatibility (DDA, C-3)
E.	Vickers Vane Pump Wear (ASTM D 2882)
F.	Dynamic Corrosion (Sundstrand Axial piston pump water Contamination, JDM-J21A Tentative)
G.	Wet-Brake Chatter (Massey-Ferguson 1135 In-Vehicle)
H.	Water Tolerance (John Deere JDM-J20A 4.6)
I.	Wet-Brake Chatter and Hydraulic Performance (AFLRL)
J.	Copper Corrosion (ASTM D 130 MODIFIED)
K.	Sonic Shear Stability Viscosity (ASTM D 2603 MODIFIED)
L.	Fluoroelastomer Compatibility (Caterpillar, TO-3)

Test I is the test which AFLRL developed in conjunction with John Deere personnel and is used to evaluate wet-brake/fluid performance in Army field tractors.(2) In previous testing (2,3,9), the frictional retention characteristics appeared to be the most critical of the selected HPTF system-evaluation tests. Therefore, the Caterpillar TO-2 Wet-clutch Friction Retention test was selected as the screening test for the various lubricants. The products which fail this test were eliminated from further

testing. The details of the twelve tests are discussed in the following sections.

V. DISCUSSION OF RESULTS

The TO-2 testing began with two MIL-L-2104C Grade 30 lubricants 8 and 9 (3) to complete the first phase series of evaluations and then in numerical sequence 10 through 19. Additional or duplicate tests were performed on lubricants 13 and 16.

A summary of the overall performance of all of these tests can be seen in Table 3, and the data from the results of these tests are shown in a subsequent table in Appendix A.

A. Wet-Clutch Friction Retention (Caterpillar Tractor Co., TO-2)

This test makes use of the SAE No. 2 Friction Test Device which has the clutch plates totally submerged in the test fluid. The device is found in most petroleum research and development laboratories, as well as independent testing laboratories. The standard SAE No. 2 Friction-Test Device is modified (10) to provide oil flow through the clutch pack to an external oil reservoir and oil cooler. Also, the clutch pack lock-up time was controlled to 1.8 seconds. Bronze-on-steel friction materials were used because most Caterpillar-built power transmissions use these materials. The results compare very favorably with the full-scale Caterpillar power shift transmission. The test criteria for a satisfactory TO-2 Friction Retention Performance are:

- Maximum Wear - bronze discs 0.25 mm (0.010 in.) total of four
  - steel plate 0.1 mm (0.004 in.) total of five
- Test Cycles - minimum cycles 15,000
- Maximum slip time increase - 20% for Grade 10 and Arctic oils
- Maximum slip time increase - 15% for all others

TABLE 3. OVERALL PERFORMANCE OF ARMY LUBRICANTS

Code	Test Procedure	10	11	12	13	14	15	16	17	18	19	20
A.	TO-2 Friction Test*	P	F	P	P	P	P	P	P	P	P	P
B.	C-3 Friction Test	P	ND	P	P	P	P	P	P	P	ND	P
C.	C-3 Pump Anti-Wear Test	P	ND	P	P	P	P	P	P	P	ND	P
D.	C-3 Seal Compatibility	P	ND	P	P	P	P	P	P	P	ND	P
E.	Vicker Vane Pump (ASTM D 2882)	P	ND	P	BF	P	P	P	P	P	ND	ND
F.	Dynamic Corrosion	P	ND	P	P	P	P	P	P	P	ND	ND
G.	Wet-Brake Chatter Massey-Ferguson 1135	P	ND	P	BP	BP	P	P	P	P	ND	ND
H.	Water Sensitivity (JDM-J20A 4.6)	F	ND	BF	P	P	P	P	P	P	ND	ND
I.	AFLRL Wet-Brake and Performance	P	ND	P	P	P	P	P	P	P	ND	ND
J.	Copper Corrosion (ASTM D 130 MOD.)	BF	ND	F	P	P	F	P	F	P	ND	ND
K.	Sonic Sheared Viscosity (JDM-J20A 4.1)	F	ND	F	F	P	P	P	P	P	ND	ND
L.	TO-3 Fluoroelastomer Compatibility	P	ND	P	P	BP	P	BP	P	BP	ND	ND

P = Pass
F = Fail
BF= Borderline Fail
ND= Not determined
BP= Borderline Pass

* Lubricants 8 and 9 passed the TO-2 Friction Test, which were reruns from previous work

Lubricants 8 and 9 were reruns from previous work (3) and passed all phases of this test. This makes the three MIL-L-2104C, Grade 30 lubricants tested in previous work (3) potential hydraulic/power transmission lubricants. These three lubricants have passed all the performed tests. Lubricants 10, 12, 14, 15, 17, and 18 passed all phases of this test. Lubricant 11 (MIL-L-21260 preservative engine oil) failed with a 30.5% maximum slip time

increase, but it passed the maximum wear phase and was eliminated from further testing. Lubricants 13, 15, 16, and 17 failed the slip time increase the first time. These four lubricants were performed with a new batch of steel plates. It was later learned that these plates produced very low results with the reference oils. The slip time curves produced by lubricants 15 and 17 (just were fails) had leveled off and were, therefore, considered a pass due to the bad plates. Lubricants 13 and 16 slip time curves had not leveled off and were therefore rerun with another batch of steel plates and this time they were a good pass. Lubricant 19 passed the screening test; however, no further evaluations were conducted. Data from this test, as well as other tests mentioned in Table 2 and Table 3, are included in the table in Appendix A.

B. Wet-Clutch Friction Retention (Detroit Diesel Allison, DDA C-3)

This test (11) also makes use of the SAE No. 2 Friction Test Device. Cooling is controlled by water flowing around the outside of the test cavity. The clutch discs are of standard resin graphite with steel plates. Except for clutch discs and fixtures, all changes were machine settings only. The C-3 test results compare favorably with full-scale DDA off-highway power shift transmissions. The test criteria for satisfactory C-3 Friction Retention performance are:

- Maximum slip time at 5500 cycles, 0.85 sec
- Minimum torque at 0.2 sec slip time at 5500 cycles, 75 ft-lb
- Maximum difference is torque at 0.2 sec slip time between 1500 and 5500 cycles, 30 ft-lb

Lubricants 10, 12, 14, 15, and 17 passed the maximum slip time phase of the test with Lubricants 13, 16, and 18 being borderline fails. Lubricants 10, 12, 14, 15, 16, and 17 passed minimum torque at 0.2 second slip time, and Lubricants 13 and 18 were borderline fails. In AFLRL judgment, all eight should be considered passes because the curves had leveled off, and this batch of steel plates produced curve levels on the very low side with the reference oils. All eight lubricants passed the difference in torque phase,

again indicating that the steel plates were borderline and that all lubricants should be considered a pass.

C. Vane Pump Antiwear (DDA C-3)

The test determines the fluid antiwear properties in a motor-driven Saginaw power steering pump at 2950 rev/min at 900 psi for 50 hours. The test criteria for satisfactory performance are:

- Cam rig grinding pattern remaining, percent
- Pump cam ring shall still show the grinding pattern for 360°
- Shall be free from scuffing, scoring, or chatter wear marks, Pressure and Thrust plate wear.

The good reference oils fall within the 80 to 85 percent of grinding pattern remaining on the pump cam ring. As can be seen in Table 4 in Reference 9, good performing lubricants do not fall below the 80-percent level. All lubricants were good passes which tend to exhibit the good overall wear characteristics of military engine oils.

D. Seal Compatibility (DDA C-3)

For this test (11), three different seal materials are used. Buna-N seal compound is subjected to hot transmission fluid, and measurements of volume and hardness are made before and after test. Silicone and polyacrylate seal compounds are subjected to hot transmission oil and to a hot air/oil vapor atmosphere, and measurements of volume and hardness are made before and after test. The test pass or fail criteria for fluid performance are:

	SAE 10	SAE 30
• Total Immersion		
Volume Change	+0.96 to 6.9%	-0.75 to 6.9%
Hardness Change	-5 to +5 pts.	-5 to +5 pts.
• Dip Cycle		
Volume Change	0 to +10%	
Hardness Change	-4 to +1%	
• Dip Cycle		
Volume Change	+1.5 to 6.5%	
Hardness Change	0 to -10 pts.	

All eight lubricants passed all phases of this test, again showing the good overall seal compatibility of the military oils.

E. Vickers Vane Pump (ASTM D 2882)

This test describes a procedure for measuring the wear characteristics of hydraulic lubricants. The test consists of a rotary vane pump operating at 1200 rpm, at 2000 psi, circulating 3 gallons of oil at a temperature of 65.6°C (150°F) or 79.5°C (175°F) for 100 hours. The results obtained are total wear (weight loss), consisting of cam ring and vane weight losses during test. The performance criteria vary among manufacturers.

- Ring Weight Loss, mg
- Vanes Weight Loss, mg
- Total Weight Loss, 50 mg max

The method has a relatively poor precision as indicated by high values of the repeatability and reproducibility random errors.(12) The manufacturers' requirement limit of 50 to 100 mg maximum weight loss is much smaller than the testing error. In this program, the 50 mg limit was assumed as performance criterion following the tentative specification for hydraulic fluids developed by the ASTM panel (3 Appendix A). Lubricants 10, 12, 14, 15, 16, 17, and 18 passed the test. Lubricant 13 failed because of a high value for the total weight loss.

F. Dynamic Corrosion (Sundstrand Axial Piston Pump Wear Contamination)

This test evaluates the hydrolytic stability of the lubricants additives and their capability to resist the dynamic corrosion in the presence of water contamination. The test determines the percent flow loss due to water contamination in a Sundstrand 22 Series Axial Piston Pump (variable displacement) using one-half of full stroke at 3100 RPM ± 100 using 5000 PSI, a reservoir temperature of 150°F ± 10°F, a loop temperature of 180° ± 10°F, 5 in. Hg. maximum inlet vacuum and 1 percent distilled water for 200 hours. This is preceded by a 25-hour start-up and break-in period with no distilled water present. The reported test data and limits are:

- Flow Loss at 5000 PSI, 10% max.

- Pump Parts Condition, Good min.
- Viscosity at 100°F
- Viscosity at 210°F
- Water Percent
- Acid No.
- Wear Metals, ppm
  - Iron
  - Copper
  - Chrome
  - Lead

Initially, all the test lubricants passed this test with the exception of lubricant 15. This lubricant was passing all phases of the test up until 183 hours, at which time it still had a good flow degradation of 1.3 percent. At this time, a crack developed in the bronze valve plate of the pump. The crack in the valve plate was not observed by the visual pretest inspection. It is possible that the bronze valve plate was a defective casting. Therefore, lubricant 15 was retested. This time, lubricant 15 passed all phases of the test. Apparently the previous test had a bad casting of bronze valve plate.

G. Wet Brake Chatter (Massey-Ferguson 1135 In-Vehicle)

The test tractor is a Massey-Ferguson Model 1135 and is equipped with a six-speed transmission incorporating a two-speed auxiliary transmission and sintered bronze brake material. The test procedure consists basically of a drain-flush-refill with test oil, and repetitive applications of left and right brakes with a recording of brake chatter under various gear-speed conditions. The chatter recording is made with a strip chart recorder in millimeters (mm) via a signal amplitude converter to obtain a numerical value. The analysis is then made to provide a comparison and ranking of the test oils. Test criteria for the reported data are:

- Low Chatter, mm 0-4
- Medium Chatter, mm 4-7 Average

- Heavy Chatter, mm 7-10
- Fail, mm 10+

This test had a change in reference oils which was required by the manufacturer. The new reference oil appears to have slightly more wet-brake chatter than did the old reference oil. Lubricants 10, 12, 15, 17, and 18 had less brake chatter than did the new reference oil. Lubricants 13 and 16 had only a slightly higher chatter rating than the new reference oil, while lubricant 14 had more (heavy) chatter. Even though the brake chatter produced from lubricant 14 was considered high, it was not to the point that it would substantially hinder operation of the vehicle but could possibly accelerate brake pad wear.

H. Water Sensitivity (John Deere JDM-J20A)

A mixture of 199.2 cm^3 of oil and 0.8 cm^3 deionized water is mixed in a blender for 60 seconds, maintaining 12,000 to 14,000 rpm. The mixture is transferred to a centrifuge tube and stored in a light-tight chamber for 7 days. The sample is centrifuged, and the percent volume of sediment is reported. The top oil phase is analyzed for metallic constituents of additives. The test criteria for a satisfactory performance are:

- Sediment, Vol%, 0.1 max
- Additive Loss, % mass, 15 max

The eight lubricants passed the additive loss phase of the test. Lubricants 13, 14, 15, 16, 17, and 18 passed the sediment volume phase of the test while Lubricants 10 and 12 failed this phase due to emulsion rather than sediment.

I. Wet Brake Chatter and Hydraulic Performance (AFLRL)

This test is performed in a John Deere Model 410 front loader/backhoe tractor. The tractor is equipped with a four-speed transmission incorporating a two-speed auxiliary transmission and graphitic wet-brake material. The test

procedure consists basically of testing the tractor with John Deere JDM-J20A lubricant, then drained, flushed, and refilled with test oil, repetitive applications of left-turn--left brake and right-turn--right brake at 57°C (135°F) and 74°C (165°F) with a recording made of that chatter with the transmission in 1st gear, second auxiliary range (fifth gear) at 800 rpm and then a comparison analysis of the chatter recording is made with the JD fluid by using a voltmeter to obtain a numerical value for ranking. The front loader and backhoe operations are timed, and brake lock-up and operating values are evaluated to provide a comparison ranking. The test criteria for satisfactory performance are:

- Wet Brake Chatter compared to JDM-J20A fluid, derived from volts
- Response Times
  - Front loader performance, seconds
  - Backhoe performance, seconds
  - Pressure Control Valve performance, pass*
  - Panic Brake Lock-up, Good min. (both wheels must lock)

In this test, three lubricants (10, 17, and 18) had lower wet-brake chatter than the John Deere reference fluid. Lubricants 12, 13, 14, 15, and, 16, had more wet-brake chatter than the John Deere fluid. Lubricants 10 and 14 had faster front/loader response times than the John Deere fluid with lubricants 10, 14, 16, and 17 also having faster backhoe response times than the John Deere fluid. None of the lubricants that had slower response times and more wet-brake chatter was considered to be excessive to the point that it would substantially hinder efficient operation of the vehicles.

J. <u>Copper Corrosion (ASTM D 130 MOD.)</u>

This test detects the corrosiveness to copper of petroleum products. A polished copper strip is immersed in 30 ml of lubricant heated to 150°C for

*As per John Deer Technical Manual-1037, Sec. 70, 5.5.

3 hours. The copper strip is removed, washed, and compared to the ASTM Copper Strip Standards. The test criterion for satisfactory performance is:

- Copper strip classification, 1b max.

Lubricants 13, 14, 16, and 18 passed this test. Lubricants 12, 15 and 17 failed, with lubricant 10 being a borderline fail. This appears to indicate that the Army engine lubricants will need additional treatment to prevent copper corrosion before these lubricants will perform well as hydraulic and power transmission fluids.

K. Sonic Shear Stability Viscosity (ASTM D 2603 MOD.)

This test covers the evaluation of the shear stability of a lubricant containing a polymer in terms of permanent loss in viscosity. The lubricant is irradiated in a sonic oscillator for 30 minutes to produce a shearing force level necessary to reduce ASTM reference Fluid A viscosity to 9.0 ± 0.1 cSt at 99°C (210°F) in five minutes and changes in viscosity are then determined by ASTM D 445. The test criteria for a satisfactory performance according to John Deere specifications (2) are:

- New Oil Viscosity, 9.1 cSt min., at 99°C
- Oil at end of 30 min. viscosity, 7.1 cSt min., at 99°C

Lubricants 14, 15, 16, 17, and 18 passed all phases. Lubricant 10 passed the viscosity loss after shear but failed the initial minimum starting viscosity. Lubricants 12 and 13 failed both phases of this test. It should be considered that these lubricants had only a 1.22 percent and 6.48 percent after shear viscosity loss and the John Deere specification allows at least 22 percent loss. These two lubricants should not be used in extremely hot climates. It is recommended that in extremely hot climates, a Grade 30 should be used. However, in spite of low viscosity, a Grade 10W oil has been successfully used in fielded JD-410 front loader/backhoe tractors at Fort Hood for three years, where summer temperatures sometimes go over 100°F.

L. Fluoroelastomer Material Compatibility (Caterpillar TO-3)

This test is conducted to determine the effect of oils on fluoroelastomer materials. Specimens of fluoroelastomer material are tested in the candidate oils along with a reference oil for 10 days (240 hr) at 150°C. A comparison of change in elongation is made to determine the fluoroelastomer/oil compatibility. The exact test limits for a satisfactory performance have not been established by the manufacturer.

Based on the manufacturer's good and bad fluoroelastomer data, the testing engineers feel that only lubricants 14, 16 and 18 should be considered poor but still acceptable, with lubricants 10, 12, 13, 15, and 17 being good passes.

M. Field Evaluations

The three John Deere Model 410 front loader/backhoe tractors in the 62nd Construction-Engineer BN at Ft. Hood, TX have been on a field test since late 1978.(2) One tractor ("D" Co.) uses the baseline lubricant, a JDM-J20A specification Type 303 fluid, and two tractors ("B" and "C" CO.) use the test lubricant, a fielded MIL-L-2104C Grade 10W (NSN 9150-01-090-5753) lubricant. These vehicles have had numerous hydraulic/transmission system problems that were not attributed to the lubricants but appeared to be operational (extremely high usage) and maintenance related.(3) During the final 15-month testing period, all vehicles reported hydraulic hose breakage/replacement and fitting leaks. The baseline tractor in "D" Company using the JDM-J20A fluid had the front main seal in the transmission replaced due to leakage. The two tractors using the MIL-L-2104C Grade 10W lubricant also had problems. The tractor in "B" Company had a transmission throwout bearing failure and replacement. The tractor in "C" Company had to replace the hydraulic pump pressure control valve. In addition, all three tractors had erratic wet-brake chatter on the left side and the tractor in "C" Company needed a clutch adjustment. After inspection of the replaced parts and vehicle log, these problems were attributed to the high usage level, maintenance, and age.

The three John Deere Model 410 front loader/backhoe tractors were evaluated for wet-brake chatter and hydraulic performance every four months. The results from the initial start of the test and September 1983, are summarized in Table 4. There does not appear to be any real significant difference in wet-brake chatter and hydraulic performance.

TABLE 4. JD 410 VEHICLE WET-BRAKE AND HYDRAULIC PERFORMANCE

Company	Fluid	Hours 12/78	Hours 9/83	Brake Chatter[a] 12/78	Brake Chatter[a] 9/83	Front Loader Performance	Backhoe Performance
B	OE/HDO-10	722	2100[b]	132	98[c]	Mod-Smooth	Mod-Smooth
C	OE/HDO-10	894	2400[b]	128	110[c]	Slow-Smooth	Mod-Smooth
D	JDM-J20A	778	2290[b]	135	102[c]	Slow-Smooth	Slow-Smooth

a/ A different recorder and chatter noise pick-up were used with the December 1978 data.
b/ All engine hour timers were not operational and had stopped at these times.
c/ The brake chatter number is derived by measuring each left and right brake application recording on a voltmeter and then totaling the results.

VI. INTERFACE WITH STANDARDIZATION ORGANIZATIONS AND INDUSTRY

A. Multipurpose Power Transmission Fluid

The Army's concern about proliferating HPTF requirements was brought to the attention of the American Society of Testing and Materials and the Society of Automotive Engineers in 1974 with a request to consider development of a multipurpose hydraulic fluid specification.(13) The Society of Automotive Engineers could obtain no agreement because each equipment manufacturer preferred its own proprietary fluid and again stated that MIL-L-2104C engine oils would produce problems if used. However, in late 1975, ASTM approved a panel to develop a multipurpose power transmission fluid specification. Personnel from AFLRL have met with this panel many times, and in early 1982 a tentative multipurpose power transmission fluid specification was approved. Appendix A of Reference 3 is a first draft of the specification in SAE-recommended practice format.

B. Fluid-Critical Hydraulic/Power Transmission Systems and Components

Results from previous efforts (3) show that numerous tests are required if all potential CCE/SMHE Components are to be addressed. The list of procured and proposed CCE/SMHE shows a broad range of equipment representing many different suppliers. Any lubricant selected for use in the CCE/SMHE hydraulic and power transmission fluid (HPTF) systems should still be acceptable for use in the Army combat/tactical fleet engines and HPTF systems. The question then arises as to whether or not military specification lubricants MIL-L-2104C/D, MIL-L-46152B, MIL-L-46167A, and MIL-H-46001C can protect all the different brands and types of components/systems during the service life of the equipment, particularly after the warranty period.

Various hydraulic and power transmission fluid systems and component manufacturers on the previously developed component list were contacted.(3) The following manufacturers were requested to identify any equipment items which they claim could not operate properly with military lubricants.

Allis-Chalmers	Ford
Barnes Corp.	General Signal Corp.
Garrison	Caterpillar
Husco	Char-Lynn
J.I. Case	International Harvester
Cessna	John Deere
Clark	Massey-Ferguson
Denison	Minneapolis-Moline
Detroit Diesel Allison	Racine
TRW Steering	Vickers
Tyrone Hydraulics	White
Sundstrand	Oliver

The majority of the manufacturers believed the proper military lubricants would operate satisfactorily in their components if the recommended viscosity is used. However, Denison and Sundstrand expressed concern with the use of multiviscosity lubricants because of the possible shear involved when used at full rated capacity. Vickers was concerned that the MIL-L-2104C and the MIL-L-46152B specifications (unlike MIL-L-46167A) did not have any pump wear tests.

All the manufacturers of tractors with wet-brakes expressed concern that the MIL-L-46001C does not have any requirements for clutch or wet-brake frictional characteristics. In addition, International Harvester, John Deere, Ford, Case, Massey-Ferguson, Minneapolis-Moline, Oliver and White expressed concern about potential wet-brake chatter noise problems when using MIL-L-2104C/D, MIL-L-46152B, MIL-46152B, MIL-L-46167, and MIL-L-46001C. It appears that these companies have not recently tested the military lubricants in questions but are basing their opinions on past experience with various lubricants.

C. Critical Component Acceptability Evaluation

The military lubricants must then be concerned with three major performance areas (1) engine protection, (2) power transmission/differential gear and hydraulic pump wear protection, and (3) wet brake/clutch protection. The engine protection is accomplished with the test requirement of MIL-L-2104C, MIL-L-46152B and MIL-L-46167A specifications, and with the new MIL-L-2104D, which will aid in power transmission operation. However, even the new MIL-L-2104D specification does not address potential differential gear and hydraulic pump wear problems, along with wet brake chatter. The revised MIL-L-46167A and MIL-L-2104D specification lubricants must meet the Allison C-3 and Caterpillar TO-2 frictional tests. Doing so should make these products acceptable for most hydraulic and power transmission applications, but possibly not for all future wet-brake systems. Therefore, the tests listed in Table 5 should be performed to assure all component acceptability.

TABLE 5. TESTS FOR EVALUATING CRITICAL COMPONENT ACCEPTABILITY

Component	Test
Rear Axle & Differential Gears	Final Drive Gear Wear Test (JDM-J20A, Procedure 5.4)
Hydraulic Pump (Full Capacity)	Denison HF-0 Piston And Vane Pump Test
Wet-Brakes	
Paper/Paper	Wet-Brake Chatter/Capacity Test (JDM-J20A Procedures 5.1 and 5.2)
Sintered/Bronze	CEC Sintered Bronze Wet-Brake Fluid Friction Test

VII. CONCLUSIONS

From the data presented and from the summarized results in Table 3, it can be seen that not all eight of the fielded MIL-L-2104C, MIL-L-46167A, MIL-L-46152B, and MIL-H-46001C lubricants passed all the bench performance and in-vehicle tests. Three MIL-L-46152B Grade 15W-40 lubricants (14, 16, and 18) passed all twelve tests. All the lubricants passed the following: (A) Wet-Clutch Friction Retention (TO-2) except lubricant 11 which was dropped from testing; (B) Wet-Clutch Friction Retention (C-3); (C) Pump Anti-Wear Properties (C-3); (D) Seal Compatibility (C-3); (F) Dynamic Corrosion (Sundstrand Axial Pump Water Contamination); (G) Wet-Brake Chatter (Massey-Ferguson); and (I) Wet-Brake Chatter and Hydraulic Performance (AFLRL) and the (L) Fluoroelastomer Compatibility Test (Caterpillar, TO-3). Lubricants 10 and 12 failed the (H) Water Sensitivity Test (John Deere). Only lubricant 13 failed the (E) Vickers Vane Pump Wear test (ASTM D 2882). Lubricants 10, 12, and 13 failed the (K) Sonic Shear Stability Viscosity Test (ASTM D 2603 MOD.) due to low initial viscosity, not because of shear. In addition, lubricants 10, 12, 15, and 17 failed the (J) Copper Corrosion Test (ASTM D 130 MOD.). This indicates that the Army lubricants may need additional treatment for copper corrosion to perform well as hydraulic lubricants.

The evaluated Army lubricants, when compared to the total number of tests, had a 90 percent pass rate. The overall data from this program appear to show that the MIL-L-46152B Grade 15W-40, the MIL-L-2104C Grade 30, and the majority of the OE/HDO-10 grade lubricants and, possibly, in cold climates MIL-L-46167 equivalent to Grade 0W-20, are good potential candidates for hydraulic and power transmission lubricants within the Army CCE/SMHE system. Also, MIL-H-46001C hydraulic machine oil had good results in this test program, but this is only one of the available products. In addition, it should be remembered that this specification has no tests to evaluate frictional characteristic performance.

VIII. RECOMMENDATIONS

Because of the continued uncertainty of whether or not the Army's lubricants will provide minimum protection in the CCE/SMHE systems, the following work plan is recommended:

(a) Since MIL-L-2104C/D specification does not provide for differential gear and hydraulic pump wear, it is proposed that the JDM-J20A Final Drive Gear Wear Test and the Denison HF-O Piston and Vane Pump Test be performed with the MIL-L-2104C OE/HDO grades 10 and 30 reference oils and with the MIL-L-46152B 15W-40 MIL-L-46167A OW-20 and the MIL-H-46001C. It is not recommended that the MIL-L-46167 equivalent to Grade OW-20 oils be tested, due to their borderline characterisitcs in pump wear and wet clutch frictional characteristics. The new MIL-L-2104D and MIL-L-46167A multiviscosity grade oils must meet the Allison C-3 and Caterpillar TO-2 frictional tests, which should make those products acceptable (frictionally) for most hydraulic/power transmission applications but these should be tested in the Denison HF-O Pump Test.

(b) Due to the wide range of wet brake friction material characteristics, two sets of friction material should be evaluated. These friction materials (papers/asbestos and sintered/bronze) should be evaluated using the JDM-J20A Wet Brake Chatter/Capacity Test and the ASTM and CEC Sintered Bronze Wet Brake Fluid Friction Test with the lubricants tested in (a).

(c) Data from these tests, (a) and (b) above, and previously collected data should be evaluated to select lubricants for field testing. The selection should be based on individual lubricant pass/fail performance. Lubricants demonstrating marginal/poor performance should be given consideration in the selection process in order to determine if slight trade-offs in performance can be tolerated in actual field operation. Consideration should also be given to lubricants tested in previous programs.

(d) Full-scale vehicle testing should be conducted to identify minimal acceptability of selected products for field application. The

types of vehicles to be tested should be minimized based on critical components identified from the test matrix.

(e) Based on the results of the full-scale testing, the suitability of various military specification lubricants for use in fielded equipment could then be determined.

IX. LIST OF REFERENCES

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2. H.W. Marbach, Jr., S.J. Lestz, and M. E. LePera, "Military Engine Oils as Hydraulic/Power Transmission Fluids in Army Commercial Construction Equipment," Interim Report AFLRL No. 113, AD A068116, conducted under Contract DAAK70-78-C-0001, U.S. Army Fuels and Lubricants Research Laboratory, San Antonio, TX, March 1979.

3. H. W. Marbach Jr. and S. J. Lestz, "Application of Military Engine Oils in Hydraulic/Power Transmission Fluid Components and Systems," Interim Report AFLRL No. 159, AD A119118, conducted under Contract DAAK70-80-C-0034, U.S. Army Fuels and Lubricants Research Laboratory, San Antonio, TX, September 1982.

4. U.S. Military Specification MIL-H-46001C, Hydraulic Fluid, Petroleum Base, For Machine Tools.

5. U.S. Military Specification MIL-L-21260C, Lubricating Oil, Internal Combustion Engine, Preservative and Break-In.

6. U.S. Military Specification MIL-L-2104C, Lubricating Oil, Internal Combustion Engine, Tactical Service.

7. U.S. Military Specification MIL-L-46167, Lubricating Oil, Internal Combustion Engine, Arctic.

8. U.S. Military Specification MIL-L-46152B, Lubricating Oil, Internal Combustion Engine, Administrative Service.

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10. J.A. McLain, "Oil Friction Retention Measured by Caterpillar Oil Test No. T02," SAE Paper No. 770512, Peoria, IL, April 1977.

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12. "Annual Book of ASTM Standards," American Society for Testing and Materials, Part 24, Test D 2882, Philadelphia, PA (1982); ASTM Technical Division N, Proposed Standard Method for Indicating the Wear Characteristics of Petroleum and Non-Petroleum Hydraulic Fluids in a Constant Volume Vane Pump (to replace D 2882), 1983.

13. Letter, MERADCOM, STSFB-GL, ASTM D2, Technical Div. B-11, Automatic Transmission Fluids, 13 August 1974.

APPENDIX A

SUMMARY OF COMPLETED TEST RESULTS

SUMMARY OF COMPLETED TEST RESULTS

Code	Test Procedure	Grade 3 MIL-46001C 10	Grade 10 MIL-21260C 11	OE/HDO-10 MIL-2104C 12	OEA 0W-20 MIL-46167 13	15W-40 MIL-46152B 14	15W-40 MIL-46152B 15	15W-40 MIL-46152B 16
a.	TO-2 Friction Characteristic Test (CAT)							
	Percent change, 15% max.	13.7	30.5	11.8	23.3 & 9.8*	12.1	17.7	19.2 & 5.6*
	4-Bronze discs, avg. wear, 0.010 in. max.	0.0042	0.0052	0.0044	0.0043 & 0.0057	0.0033	0.0050	0.0036 & 0.0031
	5-Steel plates, avg. wear, 0.004 in. max.	0.0030	0.0034	0.0020	0.0034 & 0.0026	0.0026	0.0037	0.0017 & 0.0014
	Test cycles, 15,000 min.	15,000	15,000	15,000	15,000	15,000	15,000	15,000
b.	C-3 Friction Retention Test (DDA)							
	Max. slip time @ 5500 cycles, 0.85 sec.	0.72	N.D.	0.85	0.89	0.85	0.85	0.86
	Min. torque @ 0.2 sec. slip time @ 5500 cycles, 75 ft-lbs	83	N.D.	83	73	78	81	83
	Difference in torque @ 0.2 sec. slip time between 1500 & 5500 cycles, 30 ft-lb max.	24	N.D.	13	25	12	22	12
c.	C-3 Pump Anti-wear Test (DDA)							
	Cam Rig Grinding Pattern Remaining, %	94-97	N.D.	88-91	94-97	94-97	90-93	95-98
	Scuffing, Scoring or Chattering	Tr.Scuffing	N.D.	Tr.Scuffing	Tr.Scuffing	Tr.Scuffing	Tr.Scuffing	Tr.Scuffing
	Pressure and Thrust Plate	Tr.Scuffing	N.D.	Tr.Scuffing	Tr.Scuffing	Tr.Scuffing	Tr.Scuffing	Tr.Scuffing
d.	C-3 Seal Compatibility Test (DDA)							
	Total Immersion							
	Volume Change	-1.65	N.D.	+0.12	+0.06	+0.68	+0.72	+0.15
	Hardness Change	+3	N.D.	+4	+3	-1	+4	+1
	Dip Cycle							
	Volume Change	+2.42	N.D.	+3.88	+4.46	+4.54	+3.37	+3.24
	Hardness Change	+2	N.D.	-1	-1	+1	+1	+2
	Tip Cycle							
	Volume Change	+2.38	N.D.	+3.49	+3.89	+3.54	+2.76	+3.13
	Hardness Change	-2	N.D.	-3	-3	-3	-3	-3
e.	Vickers Vane Pump Wear (ASTM D 2882)							
	Ring wt. loss, mg.	12.5	N.D	21.4	90.0	24.1	29.5	19.2
	Vanes wt. loss, mg.	2.1	N.D	2.3	3.5	2.8	1.6	4.1
	Total (100-hr Ford M2C143-A, 50 mg. max.	14.6	N.D.	23.7	93.5	26.9	31.1	23.3
f.	Dynamic Corrosion (Sundstrand Axial Piston Water Contamination)							
	Flow Degradation, 10% max.	1.3	N.D.	3.9	5.2	1.3	0.0	-1.4
	Pump Parts Condition, Good min.	Good	N.D.	Good	Good	Good	Good	Good
	Visc. @ 25 hr./225 hr. 100°F	66.4/65.2	N.D.	45.9/43.4	31.7/30.4	77.15/63.85	97.05/65.74	80.17/64.77
	Visc. @ 25 hr./225 hr. 210°F	7.1/7.9	N.D.	6.7/6.5	5.9/5.6	10.3/8.17	12.41/8.84	10.42/8.80
	H_2O @ 26 hr./225 hr.	1.13/0.16	N.D.	6.7/6.5	1.74/0.75	1.37/0.414	1.19/0.280	1.29/0.35
	Acid No. @ 26 hr./225 hr.	1.42/1.10	N.D.	2.59/3.19	3.04/2.95	2.66/2.40	2.74/2.35	2.32/3.83
	Wear Metals, ppm							
	Fe @ 25 hr./225 hr.	2/2	N.D.	1/8	9/10	12/12	3/10	4/6
	Cu @ 25 hr./225 hr.	2/5	N.D.	2/17	4/29	4/13	1/10	3/12
	Cr @ 25 hr./225 hr.	1/1	N.D.	0/0	8/65	9/7	1/1	4/4
	Pb @ 25 hr./225 hr.	3/5	N.D.	3/5	10/9	14/10	1/2	2/3
g.	Wet-Brake Chatter in Massey-Ferguson Model 1135 Tractor							
	Avg. of Reference Runs, mm							
	Min. Old 3.2 New 3.0	4.0	N.D.	1.50	4.5	6.0	4.0	4.0
	Max. Old 11.3 New 14.0	10.5	N.D.	6.50	9.5	15.5	11.0	16.0
	Avg. Old 5.8 New 6.4	5.61	N.D.	3.42	7.10	9.38	6.04	6.70
h.	Water Sensitivity (JDM-J20A)							
	Sediment, vol%, 0.1 max.	100 Emul.	N.D.	0.5 sed. 2.05 Emul.	<0.01	0.10 Emul.	<0.01	<0.01
	Additive Loss, 15% max.							
	Ca	10.0	N.D.	—	—	1.1	—	5.0
	P	12.0	N.D.	0.9	3.3	2.7	—	5.9
	Zn	4.3	N.D.	0.6	1.4	—	3.1	0.6
	Ba	—	N.D.	—	1.9	—	—	—
i.	Wet-Brake Chatter and Hydraulic Performance in JD-410 Tractor							
	Wet-Brake Chatter, derived from volts	92	N.D.	110	109	108	107	109
	Pressure Control Valve, Good min.	Good	N.D.	Good	Good	Good	Good	Good
	Front Bucket Dump @ 1500 rpm, sec.	2.4	N.D.	2.7	3.0	2.0	2.6	2.4
	Backhoe Bucket Retract @ 1500 rpm, sec.	3.0	N.D.	3.2	3.6	2.6	3.2	3.0
	Panic Brake Lock-Up, Good min.	Good	N.D.	Good	Good	Good	Good	Good
j.	Copper Corrosion (ASTM D 130)	1b/2a*	N.D.	4a/3b	1b	1b	4b/4a	1b
k.	Sonic Sheared Viscosity (ASTM D 2603)							
	New Oil, cSt 9.1 min.	8.42	N.D.	6.57	6.02	14.00	15.33	14.82
	Visc. Loss after Sonic Shear, cSt 7.1 min.	8.40	N.D.	6.49	5.63	11.32	12.48	12.03
	% change, 22 max.	0.24	N.D.	1.22	6.48	19.14	18.59	18.83
l.	Viton Compatibility Test (CAT) CAT-4569 -11.00	-3.00	N.D.	-0.85	-1.00	-38.00	-11.25	-37.81

*Duplicate Runs

Code	Test Procedure	15W-40 MIL-46152B 17	15W-40 MIL-46142B 18	15W-40 MIL-46152B 19	15W-40 MIL-46152B 20	Previous Work Reruns: Grade 30 MIL-2104-C 8	Grade 30 MIL-2104-C 9
a.	TO-2 Friction Characteristic Test (CAT)						
	Percent change, 15% max.	15.9	8.9	13.2	9.8	11.2	15.0
	4-Bronze discs. avg. wear, 0.010 max.	0.0042	0.0036	0.0046	0.0062	0.0044	0.0063
	5-Steel plates, avg. wear, 0.004 max.	0.0034	0.0023	0.0023	0.0038	0.0022	0.0043
	Test cycles, 15,000 min.	15,000	15,000	15,000	15,000	15,000	15,000
b.	C-3 Friction Retention Test (DDA)						
	Max. slip time @ 5500 cycles, 0.85 sec.	0.84	0.89	N.D.	0.76		
	Min. torque @ 0.2 sec. slip time @ 5500 cycles, 75 ft-lbs	88	74	N.D.	98		
	Difference in torque @ 0.2 sec. slip time between 1500 & 5500 cycles, 30 ft-lb max.	15	21	N.D.	20		
c.	C-3 Pump Anti-wear Test (DDA)						
	Cam Rig Grinding Pattern Remaining, %	94-96	95-98	N.D.	95-98		
	Scuffing, Scoring or Chattering	Tr.Scuffing	Tr.Scuffing	N.D.	Tr.Scuffing		
	Pressure and Thrust Plate	Tr.Scuffing	Tr.Scuffing	N.D.	Tr.Scuffing		
d.	C-3 Seal Compatibility Test (DDA)						
	Total Immersion						
	Volume Change	+0.20	+0.08	N.D.	+1.41		
	Hardness Change	+4	+3	N.D.	+1		
	Dip Cycle						
	Volume Change	+3.66	+3.46	N.D.	+5.05		
	Hardness Change	+2	+3	N.D.	-2		
	Tip Cycle						
	Volume Change	+3.53	+2.76	N.D.	+3.93		
	Hardness Change	-3	-3	N.D.	-3		
e.	Vickers Vane Pump Wear (ASTM D 2882)						
	Ring wt. loss, mg.	18.7	11.0	N.D	N.D.		
	Vanes wt. loss, mg.	3.0	1.8	N.D	N.D.		
	Total (100-hr Ford M2C143-A, 50 mg. max.	21.7	12.8	N.D.	N.D.		
f.	Dynamic Corrosion (Sundstrand Axial Piston Water Contamination)						
	Flow Degradation, 10% max.	0.7	-2.2	N.D.	N.D.		
	Pump Parts Condition, Good min.	Good	Good	N.D.	N.D.		
	Visc. @ 25 hr/225 hr. 100°F	84.26/70.20	89.66/75.10	N.D.	N.D.		
	Visc. @ 25 hr/225 hr. 210°F	10.49/9.01	11.20/9.57	N.D.	N.D.		
	H_2O @ 26 hr./225 hr.	1.10/0.38	0.66/0.16	N.D.	N.D.		
	Acid No. @ 26 hr./225 hr.	3.45/2.30	2.68/2.47	N.D.	N.D.		
	Wear Metals, ppm						
	Fe @ 25 hr./225 hr.	3/4	3/5	N.D.	N.D.		
	Cu @ 25 hr./225 hr.	4/11	4/14	N.D.	N.D.		
	Cr @ 25 hr./225 hr.	4/4	1/1	N.D.	N.D.		
	Pb @ 25 hr./225 hr.	1/2	2/2	N.D.	N.D.		
g.	Wet-Brake Chatter in Massey-Ferguson Model 1135 Tractor						
	Avg. of Reference Runs, mm						
	Min. Old 3.2 New 3.0	4.0	4.0	N.D.	N.D.		
	Max. Old 11.3 New 14.0	9.5	8.0	N.D.	N.D.		
	Avg. Old 5.8 New 6.4	5.96	6.15	N.D.	N.D.		
h.	Water Sensitivity (JDM-J20A)						
	Sediment, vol%, 0.1 max.	<0.01	<0.01 Emul.	N.D.	N.D.		
	Additive Loss, 15% max.						
	Ca	--	1.5	N.D.	N.D.		
	P	--	1.7	N.D.	N.D.		
	Zn	1.2	--	N.D.	N.D.		
	Ba	--	--	N.D.	N.D.		
i.	Wet-Brake Chatter and Hydraulic Performance in JD-410 Tractor						
	Wet-Brake Chatter, derived from volts	101	100	N.D.	N.D.		
	Pressure Control Valve, Good min.	Good	Good	N.D.	N.D.		
	Front Bucket Dump @ 1500 rpm, sec.	2.6	2.9	N.D.	N.D.		
	Backhoe Bucket Retract @ 1500 rpm, sec.	2.9	3.6	N.D.	N.D.		
	Panic Brake Lock-Up, Good min.	Good	Good	N.D.	N.D.		
j.	Copper Corrosion (ASTM D 130)	2c/3a	1b	N.D.	N.D.		
k.	Sonic Sheared Viscosity (ASTM D 2603)						
	New Oil, cSt 9.1 min.	12.65	11.40	N.D.	N.D.		
	Visc. Loss after Sonic Shear, cSt 7.1 min.	10.66	9.83	N.D.	N.D.		
	% change, 22 max.	15.73	13.77	N.D.	N.D.		
l.	Viton Compatibility Test (CAT)						
	CAT-4569 -11.00	-10.00	-40.50	N.D.	N.D.		

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